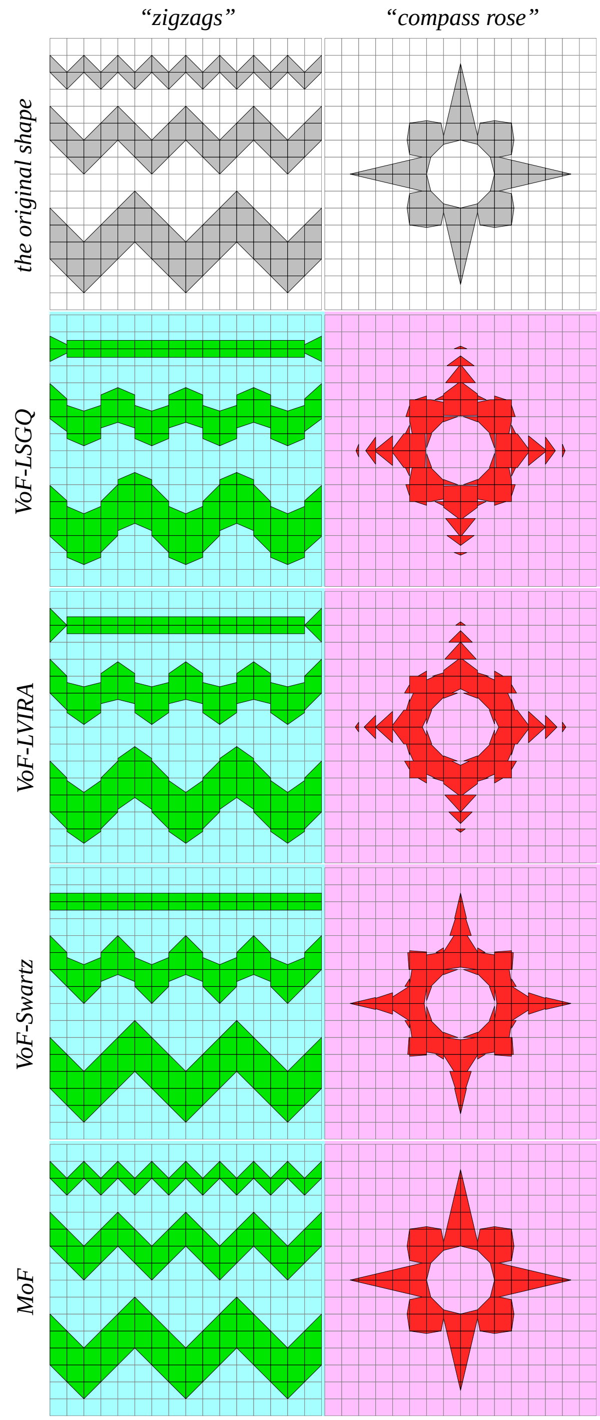
Moment-of-fluid interface reconstruction

Vadim Dyadechko vdyadechko@lanl.gov
Mikhail Shashkov shashkov@lanl.gov

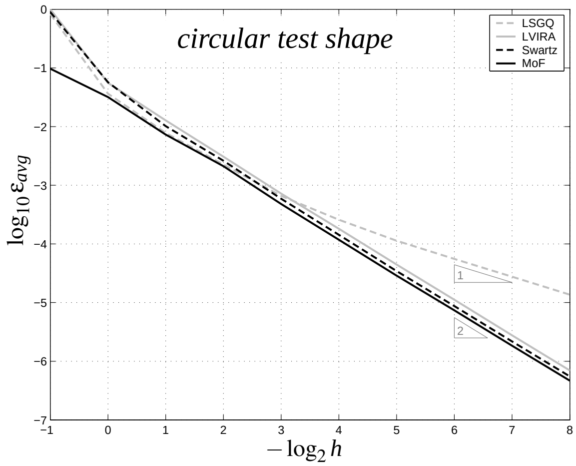
Volume-of-fluid (VoF) methods are widely used in Eulerian simulations of multi-phase flows with mutable interface topology. The strategy of VoF methods consists in calculating the interface location at each discrete moment of time from the volumes of the cell fractions occupied by different materials. Most VoF methods use a single linear interface to divide two materials in a mixed cell (Piecewise-Linear Interface Calculation (PLIC)); unfortunately the interface normal can not be evaluated without the volume fraction data from the surrounding cells, which prohibits the resulting approximation to resolve any interface details smaller than a characteristic size of the cell cluster involved in evaluation of the normal.

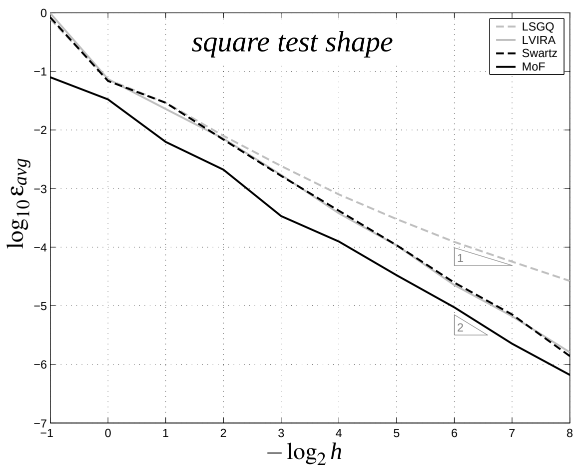
In order to overcome this inherent limitation of VoF methods, we propose to enrich the interface reconstruction input data set with *centroids of the cell fractions.* The amount of information carried by the volumes and centroids or, equivalently, by the *first two moments* of the cell fractions is sufficient to define a *mass-conservative* PLIC approximation *even without exchanging the data between the cells*. The location of the linear interface in each mixed cell is determined by *fitting the centroid of the cell fraction behind the interface to the reference one*. This strategy, called *moment-of-fluid (MoF) interface reconstruction*, (with absolute certainty) results in unique, stable, second order accurate approximation to the interfaces originally given by C^2-smooth curves; linear interfaces are reconstructed *exactly*.

With no data from the adjacent cells participating in evaluation of the interface, *the new method is able to resolve the interface details as small as the cell itself, i.e. two to three times smaller than conventional VoF-PLIC methods*. Also, since



Examples of mass-conservative interface reconstruction due to various algorithms. MoF-PLIC method demonstrates higher resolution than any of VoF-PLIC methods.





The graphs above show how the interface reconstruction error ε_{avg} (the average deviation of the reconstructed interface from the original one) scales with the mesh spacing h in case of the circular and square test shapes. The characteristic sizes of both test shapes are ≈ 1.

there is no need for the data exchange between the cells, *the grid structure is completely irrelevant for MoF interface reconstruction*.

Compared to alternative approaches, which exploit purely geometrical principles, the centroid data involvement has a clear mechanical reason. An *inexact* interface reconstruction introduces some redistribution of the fluid inside a mixed cell. This fluid motion is unrelated to any physical force presented in a discrete model. Any displacement $\Delta\mathbf{x}$ of the cell fraction centroid caused by the interface reconstruction can be interpreted as an action of an *artificial* force of magnitude $\approx m\Delta\mathbf{x}/\tau^2$ (here m is the mass of the cell fraction, and τ is the time increment). Therefore by complying with original centroids we *explicitly* reduce these artificial forces and improve the approximation properties of the discrete model of fluid dynamics.

By its design MoF algorithm results in the *minimal defect $m\Delta\mathbf{x}$ of the first moment attainable with a mass-conservative PLIC approximation*. In this sense *MoF interface reconstruction is the optimal in the class of mass-conservative PLIC methods*.

References

[1] V. Dyadechko and M. Shashkov. Moment-of-fluid interface reconstruction. Technical Report LA-UR-05-7571, Los Alamos National Laboratory, Los Alamos, NM, Oct 2005. http://math.lanl.gov/~vdyadechko/research

Acknowledgements

Funded by the Department of Energy under contract W-7405-ENG-36 and the Advanced Simulation and Computing (ASC) Program at the Los Alamos National Laboratory.

Los Alamos Report LA-UR-05-7571.